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OZONE DETERMINATIONS WITH THE NOAA SBUV/2 SYSTEM

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1. INTRODUCTION

The NOAA satellite ozone monitoring program was initiated by the National Environmental Satellite Data and Information Service (NESDIS) in December 1984, with the launch of the NOAA-9 spacecraft carrying the first operational Solar Backscatter Ultraviolet Spectrometer (SBUV/2). This instrument and its successor on NOAA-11, launched in 1988, are similar to the SBUV instrument launched by the NASA in 1978 on the Nimbus-7 research spacecraft. Measurements by the SBUV and SBUV/2 instruments overlap beginning in 1985. These instruments use measurements of the reflected ultraviolet solar radiation from the atmosphere to derive total ozone amounts and ozone vertical profiles. Since launch, the NOAA instruments and the derived products have been undergoing extensive evaluation by scientists of NOAA and NASA. Measurements obtained with these instruments are processed in real time by the NESDIS. These are reprocessed as the SBUV/2 instrument characterization is refined and as the retrieval algorithm for processing the data is improved. The NOAA-9 ozone data archive begins in March 1985 and continues through October 1990. The archive of NOAA-11 data begins in January 1989 and the data continues to be acquired in 1992.

2. ORBITAL IMPACTS

The SBUV/2 instruments are carried by the NOAA satellites launched into afternoon orbits. The first satellite to carry an SBUV/2 instrument, NOAA-9, was placed in afternoon polar orbit with a local equator crossing time of 1420 hours. The major portion of the observations by this first SBUV/2 instrument were therefore obtained near mid-afternoon local time as the satellite traversed from the Southern Hemisphere to the Northern Hemisphere. The NOAA-9 orbit drifted with time so that by the winter of 1990, the equatorial crossing time had drifted past 1800 hours. At that point in its lifetime, the satellite's orbit had passed the evening terminator and daylight observations were acquired increasingly on the southbound portion of the orbit in the early morning hours. Figure 1 shows the local equator crossing times for both NOAA-9 and NOAA-11. The similarity in the rate of change in the orbits is clearly evident with the initial equator crossing time of NOAA-11 at 1340 hours.

The drift in the orbits of the afternoon satellites has significant impacts on the acquired data. As the equatorial crossing time of the satellites advanced toward the evening terminator, the solar zenith angles associated with the SBUV/2 measurements increased. This is evident from Fig. 2 which shows the minimum solar zenith angle (SZA) in an orbit as a function of time for the two satellites. The changes in these angles with time have consequences in several areas of the data processing (Planet, 1990).

These consequences fall generally into one of three categories. The algorithm for retrieving ozone contains computations dependent on the solar zenith angle. Because the solar zenith angle changes with time and latitude, any algorithmic dependencies could appear as time or latitude dependencies in the data products. Therefore, validation efforts must be responsive to the consequences of these changes in sun angle. A second conse- quence is that the in-flight calibrations of the SBUV/2 instruments are dependent on the measurements of the solar radiation reflected from the instrument diffuser. The solar angle on the diffuser changes as the orbit drifts and a proper accounting for these changes is required in the calibration of the instruments. A third consequence, shown in Fig. 3, is the reduction in global coverage associated with the changing local time of the orbit.

In Fig. 3 the solid line depicts the global coverage of the data from NOAA-9 and the dashed line that of NOAA-11. Annual cycles are apparent with loss of data in the winter season of each hemisphere due to the high solar zenith angles. The region of loss grows in time and latitude as the observations are acquired at a later local time and the sun appears lower in the sky with each passing year. As the satellite orbit nears the terminator, the geographical regions observed in daylight change dramatically. Eventually the satellite sub-orbital track lies on or very near the terminator and all data are acquired at solar zenith angles near 90 degrees. These data are rejected because of the high solar angles and data voids occur. NOAA-9 encountered such large angles at the end of 1990.

3. GROUND TRUTH COMPARISONS

A primary means of evaluating the SBUV/2 measurements is comparison of the derived total ozone with near-simultaneous observations by stations in the ground-based Dobson network. The nadir-viewing observations by the satellite instruments have been matched in time and space with individual Dobson measurements. Monthly average differences in ozone have been computed at those Dobson stations containing at least 5 sets of coincident measurements in each month. Most of these stations are located in the mid latitudes of the Northern Hemisphere. Fig. 4 shows the time history of these monthly average differences in ozone, which are derived from about 30-40 stations. Shown are the differences in total ozone amount derived from the SBUV/2 and Dobson instruments for NOAA-9 and NOAA-11, expressed as a percentage of the Dobson value. The NOAA-9 and NOAA-11 comparisons agree quite well even with substantial differences in local time of the observations. Comparison indicates the SBUV/2 data are about 4% lower than the Dobson data. In addition, large excursions in the NOAA-9 comparisons beginning in 1989 are consequences of large changes in the temperature of the photomultiplier tube, a consequence of the orbital drift. A more reliable assessment of the different satellite measurements will be possible after improvements to the algorithm and instrument characterization are applied to the data during subsequent reprocessing.

In addition to the quantitative comparisons discussed above, we compare the total ozone generated from the data of several instruments. Fig. 5 shows a Northern Hemisphere analysis of the SBUV/2 total ozone observed by NOAA-11 on January 9, 1992. Significant features noted in the analysis are the region of high ozone values over Siberia with maximum values in the 450-465 D.U. range. A second minor peak appears over Hudson Bay. No data are shown above 63N because those regions are in darkness on this date. The lowest values (210-225 D.U.) appear above Great Britain.

Fig. 6 shows the analysis of Northern Hemisphere ozone derived from the TIROS-N Operational Vertical Sounder (TOVS) measurements (Chesters and Neuendorffer, 1990). These data are derived from infrared emission measurements and are not dependent on the presence of sunlight. A region of maximum values, over 500 D.U., is located over eastern Siberia, similar to that shown in the SBUV/2 analysis of Fig. 5. Minimum values of 240-255 D. U. are located west of Great Britain and over central Europe. Qualitatively the analyses of Figs. 5 and 6 are similar with the TOVS retrievals somewhat higher.

Fig. 7 shows a Northern Hemisphere analysis from the Total Ozone Mapping Instrument (TOMS) (Klenk et al., 1982, Herman et al., 1991) on the Nimbus-7 satellite which uses the same spectral region and essentially the same algorithm for retrieving total ozone as the SBUV/2. The agreement between these two analyses is good, although the TOMS provides greater horizontal detail because it is a scanning instrument. The maximum values measured by TOMS near the east coast of Siberia are between 450 and 475 D.U., comparing quite favorably with the 450-465 D.U. derived by the SBUV/2. Minimum values near Great Britain are 200 to 225 D.U., also agreeing well with the SBUV/2. Major features of the two analyses agree including the secondary maximum over Hudson Bay although this feature is shifted to the southwest, an effect possibly explained by the greater number of observations from the scanning TOMS instrument.

Results from the validation of the SBUV/2 vertical profiles are limited due to the requirement to validate the total ozone retrievals first. Furthermore, improved algorithms for retrieving the vertical profiles have recently been developed by NASA. Extensive validation of the SBUV/2 vertical profile data will proceed after those improvements have been incorporated in the NOAA ozone processing system.

The NOAA-11 data are considered to be the more credible data set for several reasons. A consequence of the earlier equatorial crossing time of NOAA-11 at launch is that a larger set of observations is acquired with lower solar zenith angles. In addition, our knowledge of the in-orbit calibration of the NOAA-11 instrument exceeds that of NOAA-9, which experienced problems with the onboard calibration lamp.

4. CONCLUDING REMARKS

The SBUV/2 data sets from operational NOAA satellites began in 1985. Observations are currently processed daily. These data sets are reprocessed at NESDIS as improvements to the instrument characterization and retrieval algorithm are developed. Reprocessing of the data occurs on the main-frame computers, but is being transferred to a dedicated VAXstation where the reprocessing will be accomplished more efficiently with archival of the input data and the ozone products on optical disks. These data are available to interested users by contacting Satellite Services Division, Princeton Executive Square, Suite 100, 5627 Allentown Road, Camp Springs, Maryland 20746.

Acknowledgement

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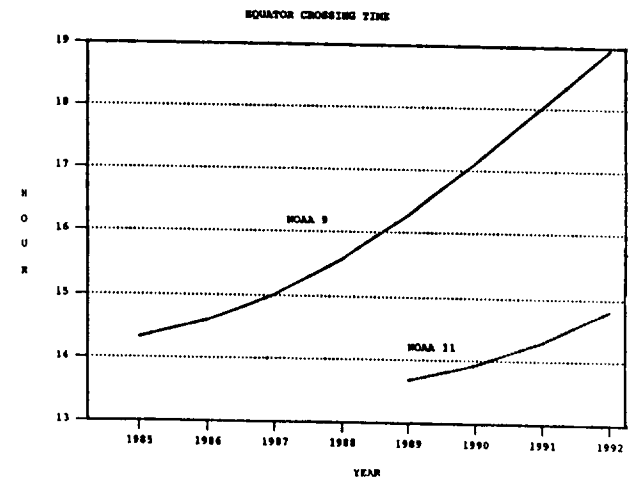

Fig. 1 Equator crossing time for NOAA-9 & 11

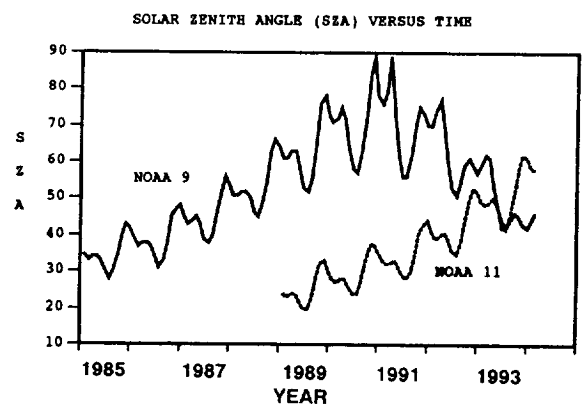

Fig. 2 Solar zenith angle versus time

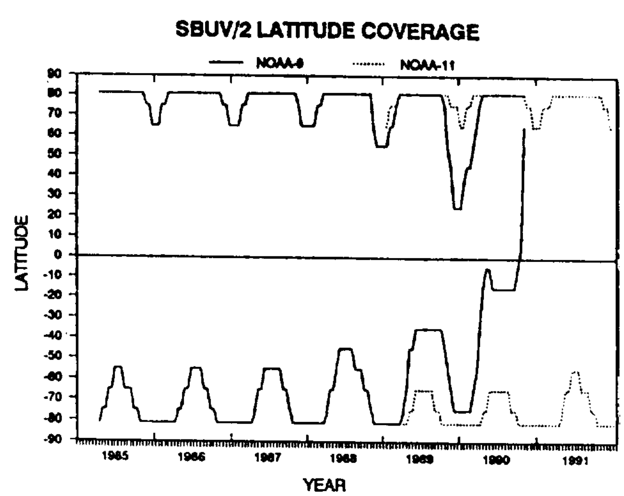

Fig. 3 SBUV/2 latitude coverage vs. time

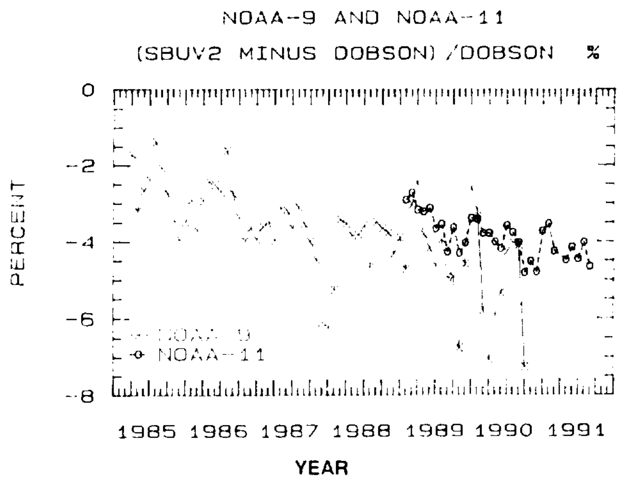

Fig. 4 Comparison of SBUV/2 and Dobson data

Fig. 6 TOVS total ozone for January 9, 1992

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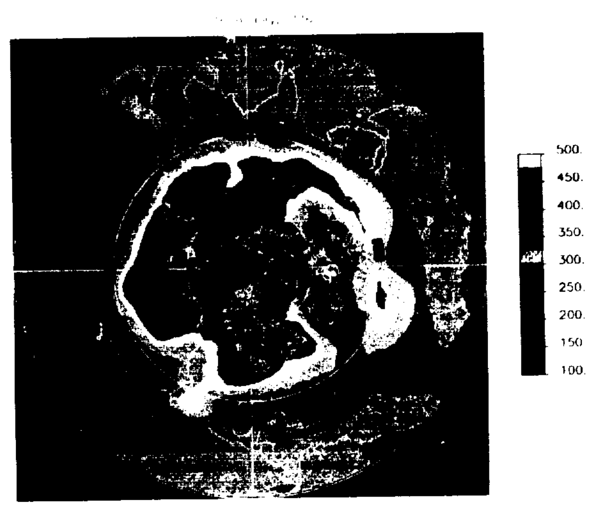

Fig. 7 TOMS total ozone for January 9, 1992